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REPORT 126542

Technical Memorandum

SYSTEM ERROR ANALYSIS

of the

H-229A

PHOTOGRAPHIC RECTIFIER

By

Approved:

INTRODUCTION

Various system approaches were considered in an effort to obtain the required improvement in accuracy for the H-229A Photographic Rectifier. Two problem areas are chiefly responsible for limiting accuracy: the cathode ray tube, and the X-Y-Table servos. Solution of both problems requires exceeding the existing state-of-the-art.

The system approach chosen utilizes the best of the current state-of-the-art advances in CRT design without requiring a lengthy, expensive research program. The error analysis for this portion of the system is based upon this assumption.

Errors introduced by the servo's can be reduced by minimizing one of the worst error contributors, friction. This will be accomplished by supporting the table on air bearings.

 STAT

Y AXIS READER TABLE ERROR

1. **Up and Down Register**

   Bit weighting of the least significant figure (bit) .0001 of inch is equivalent to $\pm 2.5 \mu$.

2. **Computer Transformer**

   The manufacturer specification of the computer transformer is $\pm 1 \mu$.

3. **A. C. Switch**

   Switching transients in the semiconductor AC Switching circuit were minimized to $\pm 2 \mu$ error by introduction of a filter.

4. **Inductosyn**

   The high accuracy positioning transducer (linear Inductosyn) contributes 2.5μ error according to the manufacturer's specification.

5. **Inductosyn Thermal Expansion**

   The material has a coefficient of expansion which contributes $\pm 1.5 \mu$ error if the temperature is being held with $\pm 2^{\circ}C$ at room temperature.

6. **Servo Positioning Error**

   The static or dynamic error of the table positioning servo is $\pm 4 \mu$ due to first and second order effect, which are; friction dead zone, non-linearity, stability, noise, acceleration loop, etc.

7. **Rate Generator**

   The proposed rate generator with ± 1 count accuracy contributes

   ± 2.5 error.

Y AXIS READER CRT ERROR

1. CRT Geometry Error

In the mathematical error analysis of the cathode ray tube the translation was introduced as an additional error source. The derivation was based on previous error analysis.

STAT

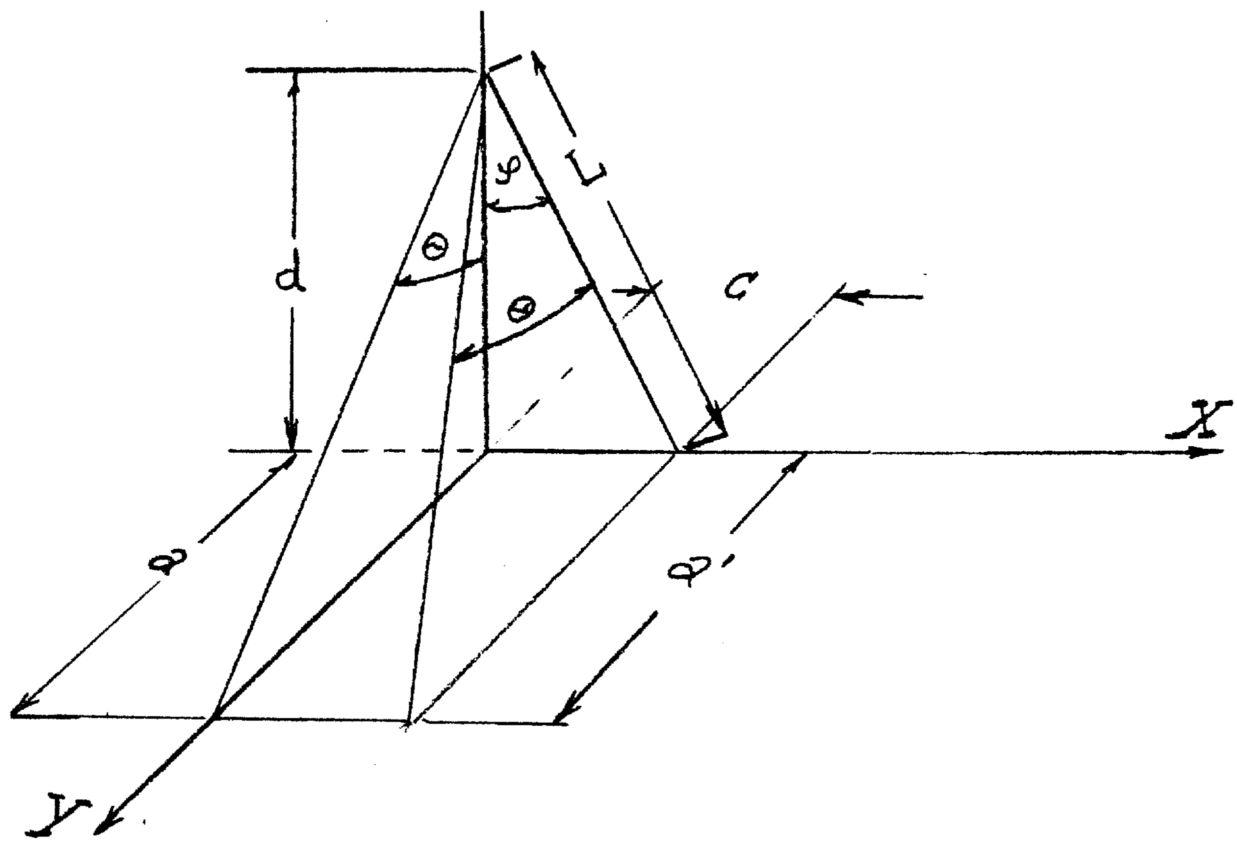


Figure 1.

Notations:

d = deflection distance

a = half scan width

θ = deflection half angle

ϑ = translational half angle

c = translational half deviation

a' = half deflection distance with translation

x' = programmed amplitude (half deflection distance)

x = deflection distance

Derivation:

Theoretically the sine of the deflection angle of an electron path from the ideal center of the tube is proportional to the magnitude of the deflecting flux of the yoke. Since the deflection flux in a uniform field is proportional to the current, the sine of the angle is proportional to the current.

Another error contributor is the optically flat face of the CRT, where the spot deflection distance is proportional to the tangent of the deflection angle.

Now by introducing translation, additional error should be considered. The two deflection components are not independent of each other. Therefore we can write the following:

$$\frac{x'}{a} = \frac{I}{I_{max}} = \frac{\sin \theta}{\sin \theta_{max}} = \frac{\sin \tan^{-1}\left(\frac{x}{d}\right)}{\sin \tan^{-1}\left(\frac{a}{d}\right)} \quad \ldots (1)$$

$$= \frac{\dfrac{\frac{x}{d}}{\sqrt{1+\left(\frac{x}{d}\right)^2}}}{\dfrac{\frac{a}{d}}{\sqrt{1+\left(\frac{a}{d}\right)^2}}} = \frac{x\sqrt{d^2+a^2}}{a\sqrt{d^2+x^2}} \qquad \ldots(2)$$

$$x' = \frac{\sqrt{d^2+a^2}}{\sqrt{d^2+x^2}} \qquad \ldots(3)$$

$$\varphi = \tan^{-}\left(\frac{c}{d}\right) \qquad \ldots(4)$$

$$L = d \sec \tan^{-1}\left(\frac{c}{d}\right) \qquad \ldots(5)$$

$$a' = a \sec \tan^{-1}\left(\frac{c}{d}\right) \qquad \ldots(6)$$

introducing translation a becomes a'

$$\Delta x = x' - x = x\left[\frac{\sqrt{d^2 + a^2\sec^2\tan^{-1}\left(\frac{c}{d}\right)}}{\sqrt{d^2+x^2}} - 1\right] \qquad \ldots(7)$$

where

Δx is the error in microns

$$\Delta x = x\left[\frac{\sqrt{d^2 + a^2\sec^2\tan^{-1}\left(\frac{c}{d}\right)}}{\sqrt{d^2+x^2}}\right] 25.4 \qquad \ldots(8)$$

Differentiating the above equation and setting the first derivative equal to zero will give the value of x which produces peak error.

$$\frac{d(\Delta x)}{dx} = x\frac{d}{dx}\left[\frac{\sqrt{d^2+a^2\sec^2\tan^{-1}\left(\frac{c}{d}\right)}}{\sqrt{d^2+x^2}}-1\right]+\left[\frac{\sqrt{d^2+a^2\sec^2\tan^{-1}\left(\frac{c}{d}\right)}}{\sqrt{d^2+x^2}}-1\right]\frac{d}{dx}x$$

$$= x\left[-\frac{d^2+a^2\sec^2\tan^{-1}\left(\frac{c}{d}\right)\frac{1}{2}\left(d^2+x^2\right)^{-\frac{1}{2}}2x}{\sqrt{d^2+x^2}}\right]+\left[\frac{\sqrt{d^2+a^2\sec^2\tan^{-1}\left(\frac{c}{d}\right)}}{\sqrt{d^2+x^2}}-1\right]\cdot$$

$$\cdot\left[\frac{\sqrt{d^2+a^2\sec^2\tan^{-1}\left(\frac{c}{d}\right)}}{\sqrt{d^2+x^2}}-1\right]+$$

$$+\,x\left[-\frac{\sqrt{d^2+a^2\sec^2\tan^{-1}\left(\frac{c}{d}\right)}\frac{1}{2}\left(d^2+x^2\right)^{-\frac{1}{2}}2x}{d^2+x^2}\right] \qquad \ldots(9)$$

$$= \left[\frac{\sqrt{d^2+a^2\sec^2\tan^{-1}\left(\frac{c}{d}\right)}}{\sqrt{d^2+x^2}}-1\right]-$$

$$-\left[\frac{2x^2}{2}\,\frac{\sqrt{d^2+a^2\sec^2\tan^{-1}\left(\frac{c}{d}\right)}\left(d^2+x^2\right)^{-\frac{1}{2}}}{d^2+x^2}\right]$$

$$\frac{\sqrt{d^2+a^2\sec^2\tan^{-1}\left(\frac{c}{d}\right)}}{\sqrt{d^2+x^2}}-1-x^2\,\frac{\sqrt{d^2+a^2\sec^2\tan^{-1}\left(\frac{c}{d}\right)}}{\left(d^2+x^2\right)^{3/2}}=0$$

$$\sqrt{d^2+a^2\sec^2\tan^{-1}\left(\frac{c}{d}\right)}\left[d^2+x^2\right]-\left(d^2+x^2\right)^{3/2}-x^2\sqrt{d^2+a^2\sec^2\tan^{-1}\left(\frac{c}{d}\right)}=0 \quad \ldots(10)$$

$$d^2\sqrt{d^2+a^2\sec^2\tan^{-1}\left(\frac{c}{d}\right)}=\left(d^2+x^2\right)^{3/2} \quad \ldots\ldots\ldots(11)$$

$$d^2+x^2=d^2\left[1+\frac{a^2\sec^2\tan^{-1}\left(\frac{c}{d}\right)}{3d^2}\right] \quad \ldots\ldots\ldots(12)$$

$$x^2=d^2\left[\frac{a^2\sec^2\tan^{-1}\left(\frac{c}{d}\right)}{3d^2}\right] \quad \ldots\ldots\ldots(13)$$

$$x=\frac{\sqrt{3}}{3}\,a\sec\tan^{-1}\left(\frac{c}{d}\right) \quad \ldots\ldots\ldots(14)$$

Since $a' = L\dfrac{a}{d}$

Therefore

$$a'=\frac{a}{d}\sqrt{d^2+c^2} \quad \ldots(15)$$

$$X = \frac{\sqrt{3}}{3} a \sqrt{1 + \left(\frac{c}{d}\right)^2} \quad \ldots\ldots\ldots\ldots\ldots (16)$$

Therefore ΔX is maximum when

$$X = \frac{a\sqrt{1 + \left(\frac{c}{d}\right)^2}}{\sqrt{3}} \quad \ldots (17)$$

Now to find the average value we have to simplify ΔX from Equation (2).

$$\Delta X = X \left[\frac{1 + \frac{a^2}{2d^2}}{1 + \frac{X^2}{2d^2}} - 1 \right] \quad \ldots\ldots\ldots\ldots (18)$$

$$\Delta X = X \left[1 + \frac{a^2}{2d^2} - \frac{X^2}{2d^2} - 1 \right] \quad \ldots (19)$$

$$\Delta X = \frac{X}{2} \frac{(a^2 - X^2)}{d^2} \quad \ldots\ldots\ldots\ldots\ldots (20)$$

Substituting $a' = a \sec \tan^{-1}\left(\frac{c}{d}\right)$

$$\Delta x = \frac{x}{2} \frac{a^2 \sec^2 \tan^{-1}\left(\frac{c}{d}\right) - x^2}{d^2} \qquad \ldots\ldots (21)$$

$$\Delta x_{average} = \frac{\int_0^{a'} \Delta x \; dx}{\int_0^{a'} dx} = \qquad \ldots\ldots (22)$$

$$= \frac{\int_0^{a'} \frac{x}{2} \frac{a^2 \sec^2 \tan^{-1}\left(\frac{c}{d}\right) - x^2}{d^2} \; dx}{\int_0^{a'} dx} \qquad \ldots\ldots (23)$$

$$= \frac{\frac{a^2 \sec^2 \tan^{-1}\left(\frac{c}{d}\right)}{2d^2} \int_0^{a'} x \, dx - \frac{1}{2d^2} \int_0^{a'} x^3 \, dx}{a'} = \qquad \ldots (24)$$

$$= \frac{x^2 a^2 \sec^2 \tan^{-1}\left(\frac{c}{d}\right)}{4 d^2} - \frac{x^4}{8d^2}$$

$$\Delta x_{average} = \frac{a^3 \sec^3 \tan^{-1}\left(\frac{c}{d}\right)}{8 d^2} \qquad \ldots\ldots (25)$$

Since minimum error occurs at 1.1 magnification, summarization of the result was based on 0.6:1, 4:1 and higher magnifications.

Using the above equations (8), (17), and (25) the values shown in the table on page 12 were obtained.

Conclusion

From the result of the analysis it is obvious that most error occurs at 4:1 magnification and at the 0.6:1 reduction. During further system analysis the value of $\pm$ 7.5 error is being used which has been derived with maximum translation.

Note

The numerical values were based on a long "neck" CRT where $d = 9.3$ inches and the use of high precision deflection components.

	TRANSLATION HALF WIDTH "c" in inches	FLAT FACE DISTORTION AND SINE RELATIONSHIP ERROR IN MICRONS				
		PRINTER CRT	PRINTER PLATEN	READER PLATEN		
				0.6:1	4:1	15:1
Δx maximum	0.750	191	31.8	-	7.9	2.1
	1.000	193	32.2	-	8.0	2.2
Δx average	0.750	135	22.5	-	5.6	1.5
	1.000	136	22.6	-	5.7	1.5
Δx average *	1.000	27.2	4.5	7.5	-	-

* Value of a = 0.900"

2. Sweep Register

Using a 13 bit up and down register calibrated for 3 inches full register, the resolution of the least significant bit will be equal to the full register sweep length/2^{12} of .00073'' = $\frac{18.5}{6}$ = $\pm 3\,\mu$.
The register will recognize both parallel (shift register) and serial (rotation rate) inputs to $\pm$ 1 count.

3. Rotation Rate Computer

The rotation rate computer must provide serial up-dating to the sweep register within $\pm$ 1 count between check intervals, which is equivalent to $\pm$ .00073 inches $\frac{25.4}{6}$ = $\pm 3\,\mu$.

4. Sweep Servo

CRT sweep length shall be controlled by an instrument servo system. The error due to the shaft positioning transducer resolution and to the first order effect is $\pm 1.5\,\mu$.

Y AXIS PRINTER TABLE ERROR

1. Inductosyn

The error contribution of the linear Inductosyn according to specification of the manufacturer is $\pm 2.5\ \mu$.

2. Inductosyn Thermal Expansion

The material has a coefficient of expansion which contributes $\pm 1.5\,\mu$ error if the temperature is being held with $\pm 2^{\circ}C$ at room temperature.

3. Servo Positioning Error

Due to the first and second order effects that positioning digitized servo contributes $\pm 4\ \mu$ error.

X AXIS READER TABLE ERROR

1. **Up and Down Register**

   Bit weighting of the least significant figure (bit) .0001 of inch is equivalent to $\pm 2.5\ \mu$.

2. **Computer Transformer**

   The manufacture specification of the computer transformer is $\pm 1\ \mu$.

3. **A. C. Switch**

   Switching transients in the semiconductor AC Switching circuit were reduced to $\pm 2\ \mu$ error by introduction of a filter.

4. **Inductosyn**

   The high accuracy positioning transducer (linear Inductosyn) contributes $\pm 2.5\ \mu$ error according to the manufacturer's specification.

5. **Inductosyn Thermal Expansion**

   The material has a coefficient of expansion which contributes $\pm 1.5\ \mu$ error if the temperature is being held with $\pm 2^{\circ}C$ at room temperature.

6. **Servo Positioning Error**

   The static or dynamic error of the table positioning servo is $\pm 4\ \mu$ due to first and second order effect, which are: friction dead zone, non-linearity, stability, noise, acceleration loop, etc.

7. **Rate Generator**

The proposed rate generator with ± 1 count accuracy contributes ± 2.5 μ error.

X AXIS CRT ERROR (READER)

1. **CRT Geometry**

Using the result of the previous derivation the error is ±1.6 μ .

2. **Sweep Register**

Using a 13 bit up and down register calibrated for 3 inches full register, the resolution of the least significant bit will be equal to the full register sweep length/2^{12} or .00073" = $\frac{18.5}{6}$ = ± 3 μ . The register will recognize both parallel (shift register) and serial (rotation rate) inputs to ± 1 count.

3. **Rotation Rate Computer**

The rotation rate computer must provide serial up-dating to the sweep register within ± 1 count between check intervals. Which is equivalent to ± .00073 inches $\frac{25.4}{6}$ = ± 3 μ .

X AXIS PRINTER TABLE ERROR

1. Inductosyn

The high accuracy positioning transducer the linear Inductosyn contributes 2.5 μ error according to the manufacturer's specification.

2. Inductosyn Thermal Expansion

The material has a coefficient of expansion which contributes $\pm$ 1.5μ error if the temperature is being held with $\pm$ 2°C at room temperature.

3. Servo Positioning Error

By positioning the table in half inch steps so called stepping servo system contributes $\pm$ 2.0 μ error.

Summary

The system error for the X and Y Table was thoroughly evaluated and summarized in the following table:

	ERROR CONTRIBUTORS	ERROR IN MICRONS X AXIS actual	X AXIS square	Y AXIS actual	Y AXIS square	
1	Up and Down Register	± 2.5	6.25	±2.5	6.25	READER TABLE
2	Computer Transformer	± 1.0	1.00	± 1.0	1.00	
3	A. C. Switch	± 2.0	4.00	± 2.0	4.00	
4	Inductosyn	± 2.5	6.25	± 2.5	6.25	
5	Inductosyn Thermal Expansion	± 1.5	2.25	± 1.5	2.25	
6	Servo Positioning	± 4.0	16.00	± 4.0	16.00	
7	Rate Generator	± 2.5	6.25	± 2.5	6.25	
8	CRT Geometry	± 1.6	2.56	± 7.5	56.25	CRT
9	Sweep Register	± 3.0	9.0	± 3.0	9.0	
10	Rotation Rate Com.	± 3.0	9.0	± 3.0	9.0	
11	Sweep Rotation	0	0	0	0	
12	Sweep Servo	0	0	± 1.5	2.25	
13	Inductosyn	± 2.5	6.25	± 2.5	6.25	PRINTER TABLE
14	Inductosyn Thermal Ex.	± 1.5	2.25	± 1.5	2.25	
15	Servo Positioning	± 2.0	4.00	± 4.0	16.00	
	TOTAL	29.6	65.56	39.0	143.00	

Peak Error at Y Axis:	39. μ
RMS Error at Y Axis:	11.9 μ
Peak Error at X Axis:	29.6 μ
RMS Error at X Axis:	8.1 μ

TOTAL SYSTEM ERROR

Peak Error:	49. μ
RMS Error:	14.4 μ

1.2 Scanning Method

The H229 method of oblique rectification by scanning is illustrated in Figure 1.2. The print is exposed in a pattern of contiguous line and strip scans. The rates and amplitudes of all printing scans are constant to insure uniform print exposure. Reading scan rates, amplitudes, and orientations are programmed in a pattern to produce the desired geometry in the uniformly printed image.

Two coordinate systems are shown in Figure 1.2. The natural coordinates (x_r, y_r, x_p, y_p) are formed by the principal point of each image (as the origins) and the principal lines (as the y axes). The machine coordinates (X_r, Y_r, X_p, Y_p) are displaced from the natural coordinates and are related to them by a scale factor.

The printing scan constants can be summarized as follows:

X_{p_o} - Scan starting position

$\Delta Y_p = \delta Y_p$ - line scan length or strip centerline separation

f_{sw} - line scan frequency (same for reading and printing)

$\overset{\circ}{X}_p$ - Strip scan velocity

δX_p - Check interval

The last constant δX_p is the spacing between raster scan check positions (X_{p1}, X_{p2}, X_{p3}, etc.). These check positions are employed by the H229 Photo Rectifier control system to improve image placement accuracy.

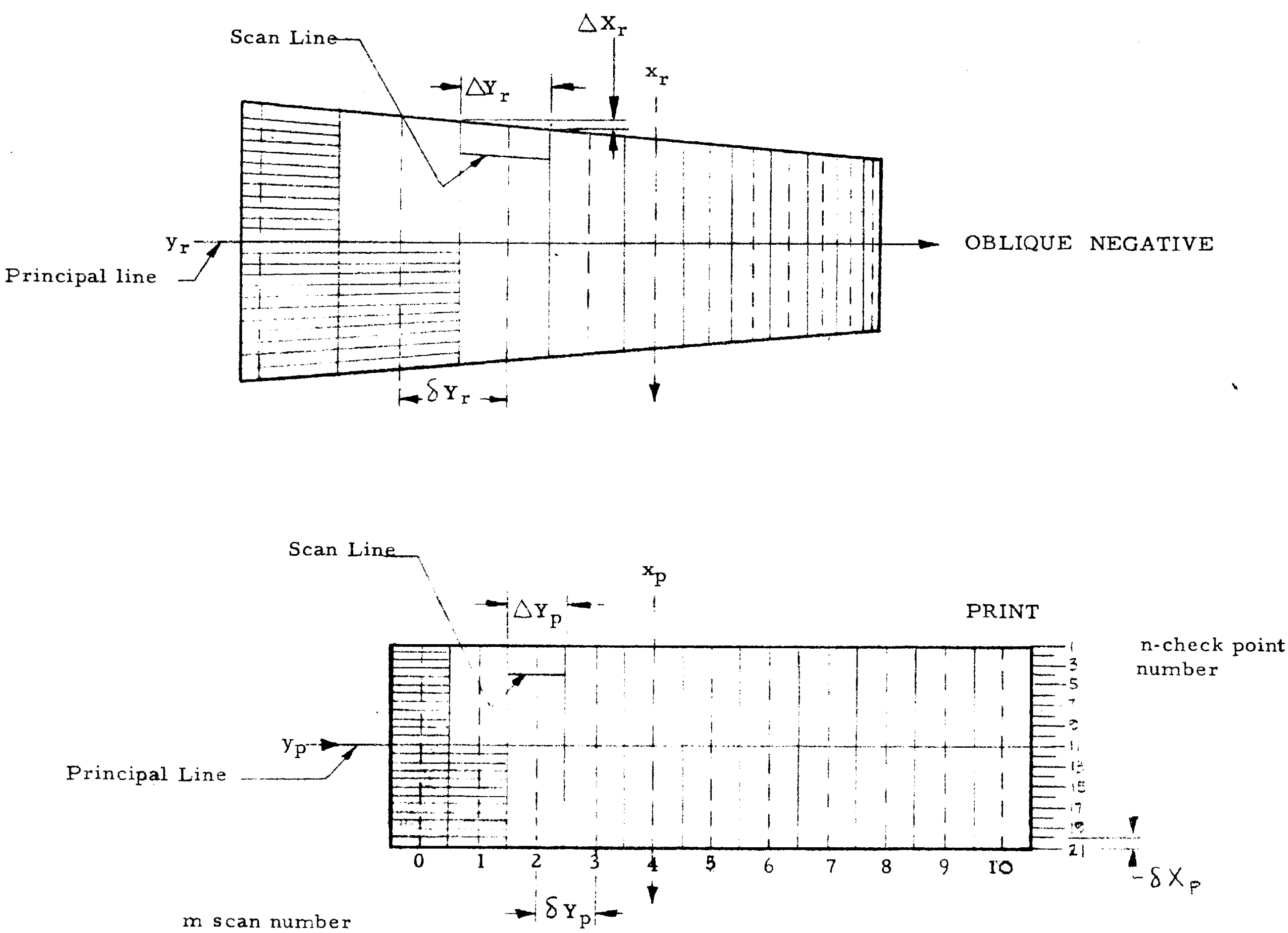

Scan Line
ΔX_r
ΔY_r
x_r
y_r
Principal line
OBLIQUE NEGATIVE
δY_r
Scan Line
x_p
ΔY_p
PRINT
n-check point number
y_p
Principal Line
0 1 2 3 4 5 6 7 8 9 10
$-\delta X_p$
δY_p
m scan number

Figure 1.2

1.2 Scanning Method (continued)

The reading scan variables to be programmed for a desired image transformation are:

X_r - starting and check positions

ΔY_r - Y component of line scan (also strip width)

ΔX_r - X component of line scan

δY_r - interval between successive strip centerlines

$\dot{X}_r$ - strip scan velocity

Reading scan parameters must be precomputed and punched in a proper sequence on the operating tape. Synchronization with printing scans and some computation are done in the H229 Photo Rectifier.

1.3 Image Transformations

Tape computation requires preliminary knowledge of the analytical transformation between coordinates of the original negative and the desired print. Using the natural image coordinates (x_r, y_r, x_p, y_p - see Figure 1.2) the relation between original and rectified images are expressed in equations 1.1 through 1.4.

Oblique Rectification

$$x_r = x_p \cdot \frac{\frac{1}{m}}{\sec t + \frac{y_p}{mf} \sin t} \qquad 1.1$$

$$y_r = \frac{y_p/m}{\sec t + \frac{y_p}{mf} \sin t} \qquad 1.2$$

1.3 Image Transformations (continued)

Panoramic Rectification

$$x_r = x_p \cdot \frac{\frac{1}{m}}{\sqrt{1 + \left(\frac{y_p}{mf} \right)^2}} \qquad 1.3$$

$$y_r = f \tan^{-1} \left[\frac{y_p}{mf} \right] \qquad 1.4$$

Parameters in the above equations that must be known or determined are:

f - camera focal length

m - isopoint enlargement ratio required

t - tilt angle

The above equations will describe most photographic rectifications likely to be made with this equipment. In general, the equipment will perform any image transformation that can be expressed by equations 1.5 and 1.6.

$$x_r = x_p \cdot F_1 (yp) \qquad 1.5$$

$$y_r = F_2 (yp) \qquad 1.6$$

2.0 Rectifier Set-Up and Program Information

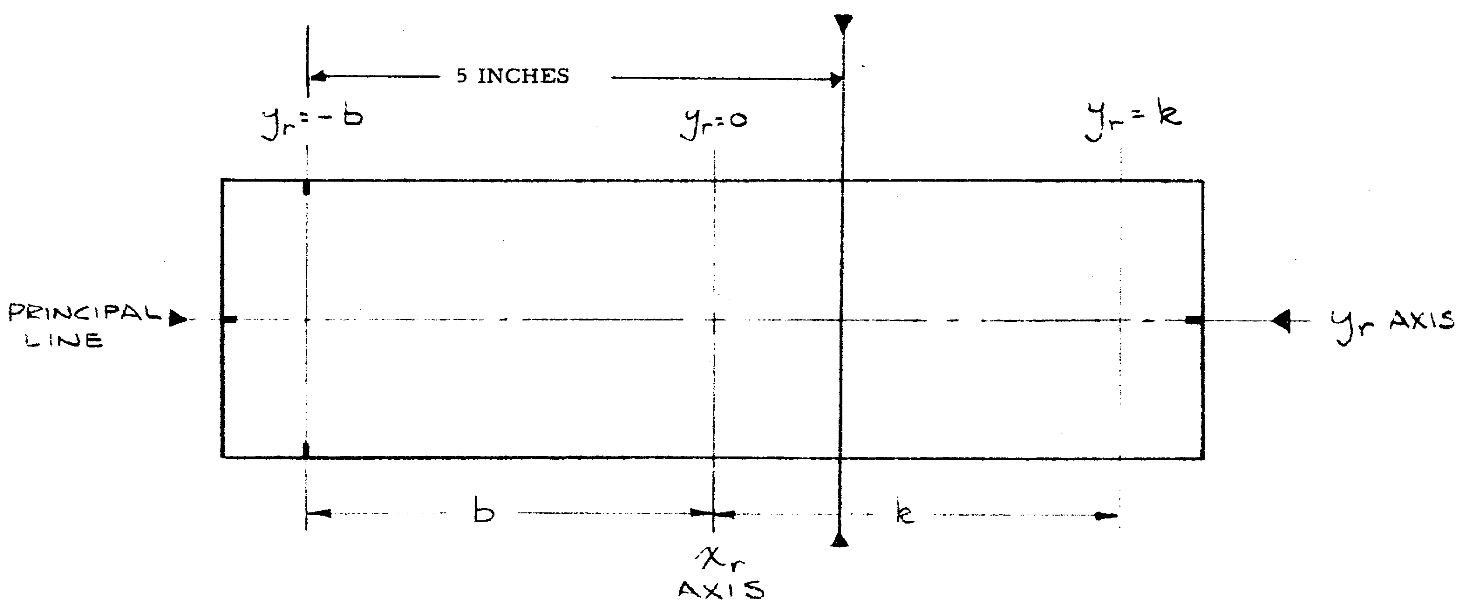
2.1 Film Annotation and Alignment

Rectification accuracy depends upon correct alignment of a properly annotated negative in the H229 reading platen and precise knowledge of the analytical image transformation. Fiducial marks on the reading platen must be aligned with the principal line of the photograph and its perpendicular at the edge. Figure 2.1 shows four markings required on the original negative to properly align the Y_r axis and the starting position $Y_r = -b + 5''$ on the platen. Two measurements are required (distance b and k).

Dimension b in Figure 2.1 is the distance from the center of the first strip scan ($y_r = -b$) to the principal point $y_r = 0$. The starting position is the low oblique edge of an oblique photograph or as high as 65° from vertical on a panoramic photograph. Dimension k is the approximate distance of principal point to the last strip scan center-line.

Information required to generate the proper rectifying program tape is

1. Type of photography (panoramic, oblique, other)
2. f - Camera Focal Length ($\pm$ 0.001 inch)
3. m - Isopoint Enlargement Ratio ($\pm$ 0.001)
4. t - Tilt angle ($\pm$ 0.01°)
5. b - (see figure 2.1) ($\pm$ 0.001 inch)
6. k - (see figure 2.1)



ORIGINAL NEGATIVE ANNOTATION

Figure 2.1

2.1 Film Annotation and Alignment (continued)

The tolerances indicated are those which will be practical within the theoretical limitations of the photo rectifier if the accuracy of measurement is achievable.

2.2 Photo Rectifier Machine Coordinate System

The numerical control system used in the H229 equipment requires that all the X and Y positions on the original negative (or print) are represented by positive numbers. This requires that the origin of machine coordinates be displaced from the principal point (used as the origin for expressing the image transformation - see equations 1.1 to 1.6). Furthermore, X displacements of the image are made by lens rather than film motion. This introduces a scale factor between coordinates. The relation between film and machine coordinates is expressed by equations 2.1 and 2.4.

$$X_r = \mu x_r + a \qquad 2.1$$

$$Y_r = y_r + b \qquad 2.2$$

$$x_p = \frac{1}{\mu} (X_p - c) \qquad 2.3$$

$$y_p = Y_p - d \qquad 2.4$$

where $\mu = \frac{25}{28}$ (exact ratio)

$a = 5.5$

$c = 5.5$

b - from annotation (see paragraph 2.1)

d - calculation from b

2.2 Photo Rectifier Machine Coordinate System (continued)

The X and Y positions in the rectifier are numerically encoded for negative and print. The negative film scan motion is sychronized with the uniform printing scans by continuous computation (in the H229) of relative scan positions and by slaving reading scans to computed positions and rates.

Figure 2.2 shows reading and printing platens with dots representing center points of selected line scans performing a specific image transformation. Starting at scan position $Y_p = 0$ ($s = 0$), a strip is scanned in the $+ X_p$ direction. The first line scan, made at $X_p = 0$ ($n = 1$) is followed by a set of line scans sweeping a strip. The starting reading scan ($X_r = 0$, Y_{rs}) is read from the punched tape at printer position ($X_p = 0$, Y_{ps}). Subsequent reading scan positions are continuously computed in the Photo Rectifier. For increased accuracy, the reading scan position is checked by the machine using precomputed tape data at intervals $\delta X_p = 1/2$ inch.

Using scan and check point numbers, the values of X_p and Y_p expressed in inches, are given by equations 2.5 and 2.6.

$$X_{pn} = (n - 1)\,\delta X_p \qquad 2.5$$

$$Y_{pn} = s\,\delta Y_p \qquad 2.6$$

From equations 2.3 and 2.4 printed image positions referred to the principal point are

$$x_{pn} = \frac{1}{\mu}\left[(n - 1)(\delta X_p - c)\right] \qquad 2.7$$

$$y_{pn} = s\,\delta Y_p - d \qquad 2.8$$

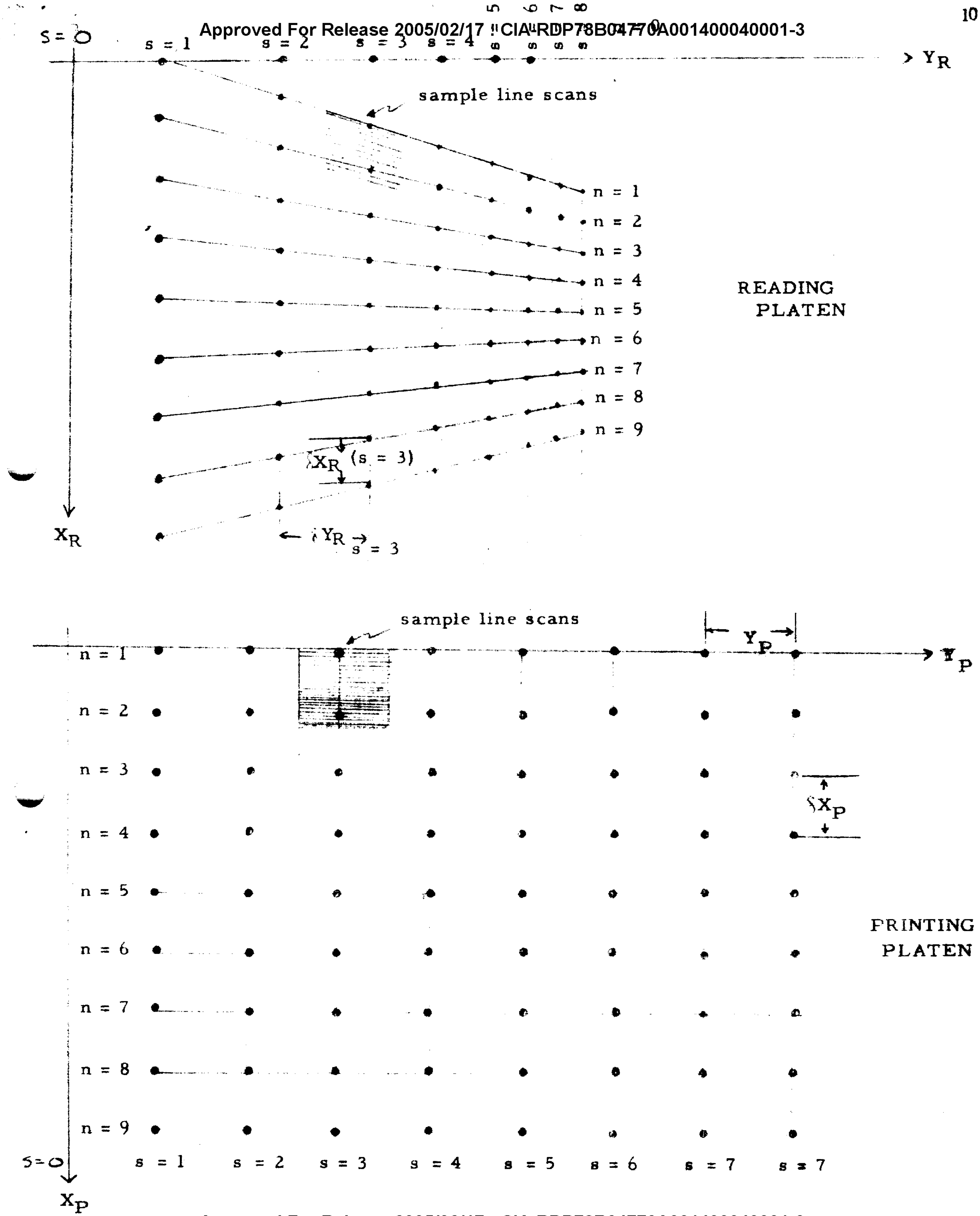

s = 0
s = 1
s = 2
s = 3
s = 4
Y_R
sample line scans
n = 1
n = 2
n = 3
n = 4
n = 5
n = 6
n = 7
n = 8
n = 9
READING PLATEN
δX_R (s = 3)
δY_R s = 3
X_R
sample line scans
Y_P
δX_P
PRINTING PLATEN
s = 0
s = 1
s = 2
s = 3
s = 4
s = 5
s = 6
s = 7
s = 7
X_P

Figure 2.2

2.2 Photo Rectifier Machine Coordinate System (continued)

The value interval δX_p is always 0.5000 inch. The value of δY_p will be 0.5000 inch or less. The exact value of δY_p is determined by setting the largest value of δY_r equal to 0.5000 inch if it exceeds δY_p.

The H229 Photo Rectifier employs check points from (n = 1 to n = 21). The number of scans S depends upon the length of the rectified image.

2.3 Punched Tape Program

Numerical Data required to program each reader scan in synchronism with the corresponding printing scan is given below:

a. δY_{rs} - interval between the centerline of the (s - 1)th reading scan and the Sth scan.

b. ΔY_{rs} - Y component of reading line scans in the Sth strip scan.

c. $\frac{\Delta X_{rs}}{x_{rs}}$ - X component of any reading line scan (in the Sth strip) divided by the displacement of its center point from the principal line. This constant for each reading strip scan is used to compute the value ΔX_{rs} in real time

d. $\dot{X}_p/\dot{X}_r$ - ratio of printing and reading strip scan velocities.

e. $X_{rs,n}$ - instantaneous X_r position of line scan centers used for check points.

2.3 Punched Tape Program (continued)

Five On-Off commands are also required from punched tape. These are Register, Start Scan, Stop Scan, Stop Program, and Sweep Aspect.

Punched tape is read in the H229 Tape Reader in blocks of 5 x 10 hole positions. Each strip scan requires 22 tape blocks. Tape block n = 0 contains all numerical constants for the scan. Tape blocks n = 1 through 21 contain data for checking scan positions in 1/2 inch printing scan intervals. The number n referes to the check point (figure 1.2) and also the tape block containing the numerical reading check point position. Since each scan requires 22 tape blocks (n = 0 through 21) the total number of 5 x 10 hole position blocks in the program tape is 22 x (s + 1) where s varies from 0 to S.

Numerical information in each Data Block (that is where n = 0) is shown in Figure 2.3. δY_r is expressed by four decimal digits; Y_r by an eleven bit binary number; and $\frac{\Delta X_r}{x_r}$ by a nine bit binary number.

In Figure 2.4 X_r is expressed as a seventeen bit binary number and $\overset{o}{X}_p / \overset{o}{X}_r$ as a fourteen bit binary number.

Sprocket Holes

ROW NO.	A	B	C	D	E	F	G	H
P = 1	δY_r	δY_r	δY_r	δY_r MSD		*	*	*
2	δY_r	δY_r	δY_r	δY_r		*	*	*
3	δY_r	δY_r	δY_r	δY_r		*	*	*
4	δY_r	δY_r	δY_r	δY_r		*	*	*
5	ΔY_r	ΔY_r	ΔY_r	ΔY_r	ΔY_r MSD	*	*	*
6	ΔY_r	ΔY_r	ΔY_r	ΔY_r	ΔY_r	*	*	*
7	*				ΔY_r	*	*	*
8	$\frac{\Delta X_r}{X_r}$	$\frac{\Delta X_r}{X_r}$	$\frac{\Delta X_r}{X_r}$	$\frac{\Delta X_r}{X_r}$	$\frac{\Delta X_r}{X_r}$ MSD	*	*	*
9	*	$\frac{\Delta X_r}{X_r}$	$\frac{\Delta X_r}{X_r}$	$\frac{\Delta X_r}{X_r}$	$\frac{\Delta X_r}{X_r}$	*	*	*
10	R				S.A.	DB	BI	*

* Position never used

R - Register Command

S. A. -Sweep Aspect

MSD - Most Significant Bit

DB - Data Block

BI - Block Indicator

Figure 2. 3

Sprocket Holes (between columns C and D)

ROW NO.	A	B	C	D	E	F	G	H
P = 1	X_r	X_r	X_r	X_r	X_r MSD	*	*	*
2	X_r	X_r	X_r	X_r	X_r	*	*	*
3	X_r	X_r	X_r	X_r	X_r	*	*	*
4				X_r	X_r	*	*	*
5	$\mathring{X}_p / \mathring{X}_r$	$\mathring{X}_p / \mathring{X}_r$	$\mathring{X}_p / \mathring{X}_r$	$\mathring{X}_p / X_r$	$\mathring{X}_p / \mathring{X}_r$ MSD	*	*	*
6	$\mathring{X}_p / \mathring{X}_r$	$\mathring{X}_p / \mathring{X}_r$	$\mathring{X}_p / \mathring{X}_r$	$\mathring{X}_p / \mathring{X}_r$	$\mathring{X}_p / \mathring{X}_r$	*	*	*
7	*	$\mathring{X}_p / \mathring{X}_r$	$\mathring{X}_p / \mathring{X}_r$	$\mathring{X}_p / \mathring{X}_r$	$\mathring{X}_p / \mathring{X}_r$	*	*	*
8						*	*	*
9	*					*	*	*
10		START SCAN	STOP SCAN	STOP PRO-GRAM			BI	*

* - Position never used

MSD - Most significant Bit

B.I. - Block Indicator

CHECK BLOCK ($n \neq 0$)

Figure 2.4

2.3 Punched Tape Program (continued)

a. δY_{rs} representation

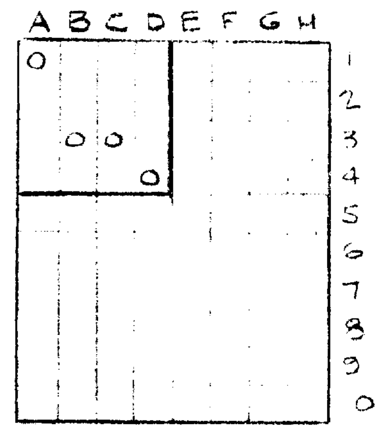
The value of δY_{rs} is expressed as a four place decimal digit. Each digit is coded on the program tape as a binary-coded decimal number. For instance, $\delta Y_{rs} = 0.1068$ inch it would be coded:

0001 first digit

0000 second digit

0110 third digit

1000 fourth digit



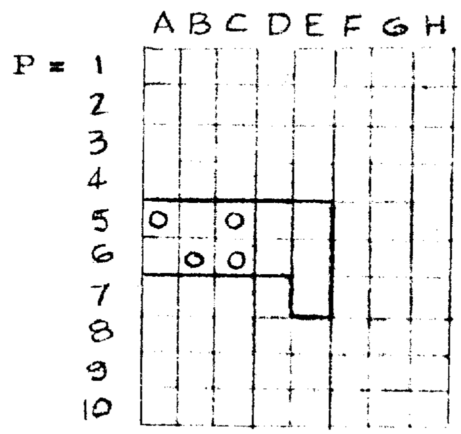
The value of δY_{rs} is the only decimally coded quantity used.

2.3 Punched Tape Program (continued

x b. ΔY_{rs} representation

The value of ΔY_{rs} is multiplied by a scale factor (3500). For instance, if $\Delta Y_{rs} = 0.09651$ inch the machine value would be $\Delta Y_{rs} = 334$ and would be expressed as follows:

$\Delta Y_r = 00101001100$ units

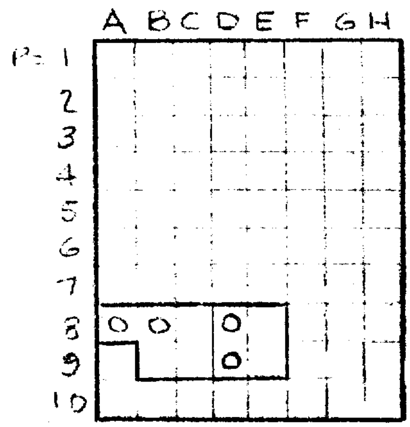


c. $\frac{\Delta X_{rs}}{x_{rs}}$ representation

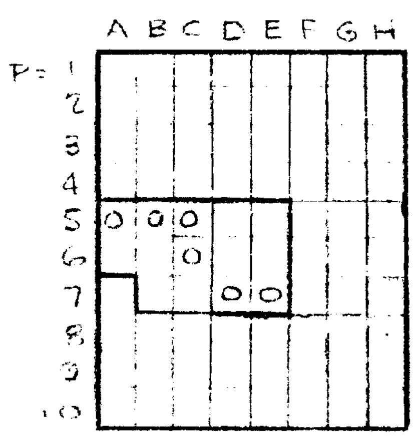
The value of $\frac{\Delta X_r}{x_r}$ is multiplied by a scale factor (10,000). Consider the case where the maximum occurs at a 65° viewing angle when $Y_p = 12$ inches. If the ratio $\Delta X_{rs}/x_{rs} = 0.018$, the machine value is 180 expressed as follows:

2.3 Punched Tape Program (continued)

$$\frac{\Delta X_{rs}}{x_{rs}} = 010110100 \text{ units}$$



d. $\frac{\dot{X}_{ps}}{\dot{X}_{rs}} = \frac{\dot{x}_{ps}}{\dot{x}_{rs}}$ This value is multiplied by a scale factor of 2^9 and 7 is subtracted from the product. For instance, if $\frac{\dot{X}_{ps}}{\dot{X}_{rs}} = 7.361$, $(2^9 \times 7.361) - 7 = 3669-7$. $\frac{\dot{X}_{pm}}{\dot{X}_{rm}}$ is represented in the tape as the binary number 00111001001100 and is stored in a 14-bit register.



2. 3 Punched Tape Program (continued)

e. $X_{rs,n}$ representation

This value is calculated from the equation:

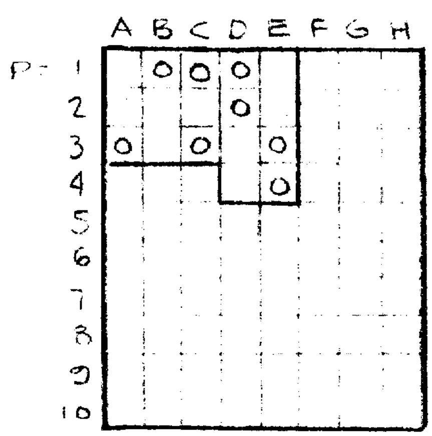
$$X_{rs,n} = \mu x_{rs,n} + a$$

where $a = + 5.500$ inches

and $\mu = \frac{25}{28}$

This number is stored by the machine in a 17-bit register. The numerical value of $X_{rs,n}$ is expressed as 2^{13} machine units per inch. For instance, if $X_{rs,n} = 7.136$, its numerical machine value is 58, 458 machine units and is expressed:

$$X_{rs,n} = 01110010001010110$$



This data is summarized on page 18a.

Scan Number	Check Point Number	Row Number	Command	Bits Registered
$0 \leqq s \leqq S$	0	0	δY_{rs}	1st decimal digit
"	0	1	δY_{rs}	2nd decimal digit
"	0	2	δY_{rs}	3rd decimal digit
"	0	3	δY_{rs}	4th decimal digit
"	0	4	ΔY_{rs}	2^{10} through 2^6
"	0	5	ΔY_{rs}	2^5 through 2^1
"	0	6	ΔY_{rs}	2^0
"	0	7	$\frac{\Delta X_{rs}}{x_{rs}}$	2^8 through 2^4
"	0	8	$\frac{\Delta X_{rs}}{x_{rs}}$	2^3 through 2^0
"	0	9	Reserved for ON-OFF Commands	
"	$0 < n < 23$	0	$X_{rs,n}$	2^{16} through 2^{12}
"	"	1	$X_{rs,n}$	2^{11} through 2^7
"	"	2	$X_{rs,n}$	2^6 through 2^2
"	"	3	$X_{rs,n}$	2^1 through 2^0
"	"	4	$\dot{X}_{rs}/\dot{X}_{rs}$	2^{13} through 2^9
"	"	5	$\dot{X}_{ps}/\dot{X}_{rs}$	2^8 through 2^4
"	"	6	$\dot{X}_{ps}/\dot{X}_{rs}$	2^3 through 2^0
"	"	7	Not used	
"	"	8	Not used	
"	"	9	Reserved for ON-OFF Commands	

3.0 Computation

3.1 General

Before a program tape can be generated, the rectification to be performed and the image size must be known. The general analytic transformation to be performed is as follows:

$$x_r = x_p \cdot F_1 (y_p) \qquad 1.5$$

$$y_r = F_2 \cdot F_2 (y_p) \qquad 1.6$$

It is defined by

1. Type of photography
2. Camera Focal Length
3. Isopoint Enlargement Ratio (from altitude)
4. Tilt Angle (in oblique photography)

The boundaries of the image are established by the printing platen size ($9\frac{1}{2}$ inch film) and

1. m - Isopoint Enlargement Ratio
2. b - Starting position distance of Y_r axis from principal point
3. k - Approximate end point distance on Y_r axis from principal point

Before tape program computation it is also necessary to know:

1. δX_p - check point interval = 0.5''
2. δY_p - printing strip width
3. N - number of check points $0 \leqq n \leqq N = 21$
4. S - number of strip scans required $0 \leqq s \leqq S$
5. d - starting point on Y_p axis
6. q = 1 High Operating Speed

q [illegible] Low Operating Speed

3.1 General (continued)

7. ΔY_r scale factor - 3,500

8. $\Delta X_r / x_r$ scale factor - 10,000

9. a - X_r starting position

10. c - X_p starting position

Values determined by the H229 Photo Rectifier design are:

$\delta X_p = 0.5000$ inch

N = 22, that is, n varies from 0 to 21

a = 5.5 inches

c = 5.5 inches

Values to be determined by preliminary calculations are δY_p, S, d, q.

The logical structure of program computation and tape readout also requires knowledge of the sequence of logical and numerical commands. See Section 3.3.

3.2 Preliminary Calculation and Subroutines

Formulas for preliminary calculation are determined by the equations of rectification (equation 1.5 and 1.6)

Calculation of δY_p

Panoramic

$\delta Y_p = 0.5000$ inch if $m \geq 1$

$\delta Y_p = 2F_2^{-1}$ ($y_r = 0.2500$ inch) if $m < 1$

Note F_2^{-1} and F_1^{-1} used for inverse function)

3.2 Preliminary Calculation and Subroutines (continued)

Calculation of δY_p

Oblique

$$\delta Y_p = F_2^{-1}(-b + 0.2500'') - F_2^{-1}(-b - 0.2500'')$$

or 0.5000 inch, whichever is less.

Calculation of S

$$S = \text{Modulate } \frac{F_2^{-1}(k) - F_2^{-1}(-b)}{\delta Y_p} \text{ to next higher number}$$

Calculation of d

$$d = -F_2^{-1}(-b)$$

Calculation of q

$q = 1$ (High Speed) if $m \geq 2$

$q = 2$ (Low Speed) if $m < 2$

3.2 Preliminary Calculation and Subroutines (continued)

Preliminary and program computation involves calculation with functions that will be required computer subroutines. Using equations 1.5 and 1.6, the tape data computation will require use of the following equations.

Equations for Program Calculations

1. $$\delta Y_{rs} = \left\{ F_2 \left[s \ \delta Y_p - d \right] - F_2 \left[(s - 1) \ \delta Y_p - d \right] \right\} \times 10^4$$

where $\delta Y_r \triangleq 0$

Calculation accuracy - to nearest whole number

2. $$\Delta Y_{rs} = \left[3,500 \right] \times \left[F_2 \left\{ (s + \tfrac{1}{2}) \ \delta Y_p - d \right\} - F_2 \left\{ (2 - \tfrac{1}{2}) \ \delta Y_p - d \right\} \right]$$

Calculation accuracy - to nearest whole number

3. $$\left[\frac{\Delta X_r}{x_r} \right]_s = \left[10,000 \right] \times \left[\frac{F_1 \left\{ (s + \tfrac{1}{2}) \ \delta Y_p - d \right\} - F_1 \left\{ (s - \tfrac{1}{2}) \ \delta Y_p - d \right\}}{F_1 \left\{ s \ \delta Y_p - d \right\}} \right]$$

Calculation accuracy - to nearest whole number

3.2 Preliminary Calculation and Subroutines (continued)

Equations for Program Calculations

4. $$x_r(n,\ s) = \left[\left\{(n-1)\ \delta X_p - c\right\} \times \left\{F_1\,(s\ \delta Y_p - d)\right\} - a\right] \times 2^{13}$$

Calculation accuracy - to nearest whole number

5. $$\left[\frac{\overset{o}{X}_p}{\overset{o}{X}_r}\right]_s = \frac{2^9 \times q}{F_1\left[s\ \delta Y_p - d\right]} - 7$$

Calculation accuracy - to nearest whole number

The scale factors shown are required for the coding used for numerical registers in the Photo Rectifier.

The required calculation will use the following functional subroutines:

1. $$\frac{x_p}{\mu} = (n-1)\ \delta X_p - c$$

2. $$y_p = s\ \delta Y_p - d$$

3a. $$F_1\,(y_p) = \frac{\frac{1}{m}}{\sqrt{1 + \left(\frac{y_p}{mf}\right)^2}}$$ Panoramic

3b. $$F_1(y_p) = \frac{\frac{1}{m}}{\sec t + \frac{y_p}{mf} \sin t}$$ Oblique

4a. $$F_2(y_p) = F\ \tan^{-1}\left(\frac{y_p}{mf}\right)$$ Panoramic

4b. $$F_2(y_p) = \frac{\frac{y_p}{m} \cos t}{\sec t + \frac{y_p}{mf} \sin t}$$ Oblique

3.2 Preliminary Calculation and Subroutines (continued)

5a. $F_2^{-1}(Y_r) = mf \tan \frac{(y_r)}{f}$ Panoramic

5b. $F_2^{-1}(y_r) = \dfrac{m\, y_r \sec t}{\cos t - \frac{y_r}{f} \sin t}$ Oblique

On-Off Command logic must also be programmed into automatic computations. In terms of check block number (n), scan number (s) and tape block row number (p) the logic of these commands is given below.

Machine Command Logic

Command	Logic
9A (register)	If n = 0 and p = 9
9B (Start Scan)	If n = 1 and p = 9
9C (Stop Scan)	If n = 21, and p = 9
9D (Stop Program)	If n = 21, p = 9, and s = S
9E (Sweep Aspect)	If n = 0, p = 9, and $\frac{\Delta x_r}{X_r}$ is negative

3.3 Computation Sequence

The sequence of program computation and tape punch is described by the machine operating program (section 2.3). This sequence is collected on the following table.

COMPUTATION AND TAPE PUNCH SEQUENCE

	Step	Command	Operation	Store
	1	Start	Clear s, n, & p counters	
From Step 26c	2	n=0, p=0	Compute δY_{rs}	Register δY_{rs}
	3	Reg δY_{rs}	Punch 1st decimal digit	p + 1
	4	n=0, p=1	Punch 2nd decimal digit	p + 1
	5	n=0, p=2	Punch 3rd decimal digit	p + 1
	6	n=0, p=3	Punch 4th decimal digit	p + 1
	7	n=0, p=4	Compute ΔY_{rs}	Register ΔY_{rs}
	8	Reg. ΔY_{rs}	Punch bits 2^{10} to 2^6	p + 1
	9	n=0, p=5	Punch bits 2^5 to 2^1	p + 1
	10	n=0, p=6	Punch bits 2^0	p + 1
	11	n=0, p=7	Compute $\left[\frac{\Delta X_r}{X_r}\right]_s$	Register $\left[\frac{\Delta X_r}{X_r}\right]_s$
	12	Reg $\left[\frac{\Delta X_r}{X_r}\right]_s$	Punch bits 2^8 to 2^4	p + 1
	13	n=0, P=8	Punch bits 2^3 to 2^0	p + 1
	14	n=0, P=9	a. Punch reg. command 9A b. Punch sweep ascpect (9E) If $\frac{\Delta X_r}{X_r}$ is negative	p + 1, N + 1
From Step 26b	15	n≠0, p=0	Compute X_r (s, n)	Register X_r (s, n)
From Step 26a	16	Reg. X_r (s, n)	Punch bits 2^{16} to 2^{12}	p + 1
	17	n≠0, p=0	Punch bits 2^{11} to 2^7	p + 1
	18	n≠0, p=2	Punch bits 2^6 to 2^2	p + 1
	19	n≠0, p=3	Punch bits 2^1 to 2^0	p + 1
	20	n≠0, p=4	Compute $\left[\frac{\overset{o}{X}_p}{\overset{o}{X}_r}\right]_s$	Register $\left[\frac{\overset{o}{X}_p}{\overset{o}{X}_r}\right]$
	21	Reg $\left[\frac{\overset{o}{X}_p}{\overset{o}{X}_r}\right]$	Punch bits 2^{13} to 2^9	p + 1
	22	n≠0, p=5	Punch bits 2^8 to 2^4	p + 1
	23	n≠0, p=6	Punch bits 2^3 to 2^0	p + 1
	24	n≠0, p=7		p + 1
	25	n≠0, p=8		p + 1
To Step No. 15	26a	n=1, p=9	Punch start scan (9B)	p + 1, n + 1
To Step No. 15	26b	1<n<21, p=9		p + 1, n + 1
To Step No. 2	26c	n=21, p=9	Punch stop scan (9c)	p + 1, n + 1, s + 1
	26d	n=21, s=S, p=9	Punch stop program (9d)	Stop computer

3.3 Computation Sequence (continued)

A general flow diagram for the automatic computation is shown in Figure 3.1. After data for rectification of specific negative is stored, computation is started. Counters n and s are set to zero. Counter n is cyclic.

Preliminary computation is accomplished by interrogating storage for data required and through the proper subroutines. After preliminary calculations, scan program calculation is started. Calculation and tape punch is made for n = 0, 5 = 0. When the first data block has been punched the n counter is stepped and the first check block is computed. After each check block the n counter is stepped and the routine is repeated.

After 21 check blocks have been punched (the n counter is full), the S counter is stepped and the next scan block set computed.

3.4 Sample Programs

Three test program tapes are used to check out the Rectifier; two enlargements (1:1 and 4:1) and a panoramic rectification. Data for these are given below:

1. 4:1 Enlargement

Oblique transformation

f = 6 inches

m = 4

t = 0 degrees of arc

b = 2 inches

k = 2 inches

3.4 Sample Programs (continued)

2. 1:1 Enlargement

Oblique Transformation

f = 12 inches

m = 1

t = 0 degrees of arc

b = 9 inches

k = 9 inches

3. Panoramic Rectification

Panoramic Transformation

f = 3 inches

m = 4

b = 3.405

k = 3.405

4. A desirable Oblique rectification is oblique transformation.

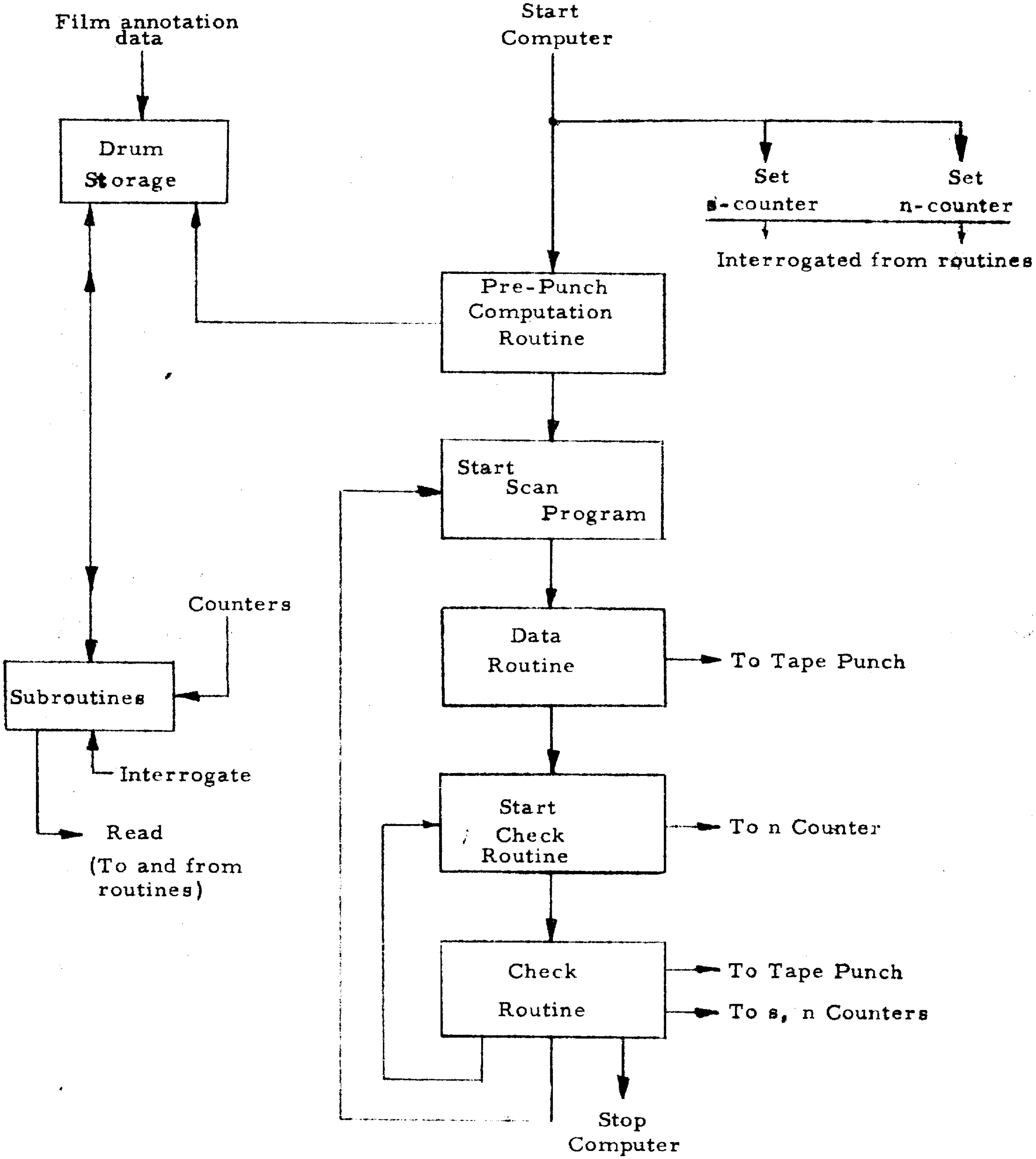
f = 6 inches

m = 1

t = 21 degrees of arc

b = 4.5 inches

k = 4.5 inches



FLOW DIAGRAM OF H229
TAPE COMPUTATIONS AND PUNCH

Figure 3.1

4.0 Appendix

4.1 Symbols Used

x_r, y_r	natural image coordinates, negative
x_p, y_p	natural image coordinates, print
X_r, Y_r	Machine platen coordinates, Reader
X_p, Y_p	Machine platen,coordinates, Printer
ΔY_p	Printing line scan width
ΔY_r	Reading line scan, y component
ΔX_r	Reading line scan, x component
δY_p	Distance between adjacent printing scan centers
δY_r	Distance between adjacent reading strip centerlines
δX_p	Check point spacing
$\mathring{X}_r$, $\mathring{X}_p$	Strip scan rates
n	Check point (or tape block) number
s	Scan number
m	Enlargement ratio
f	Camera focal length
t	tilt angle
F_1 & F_2	arbitrary functions
a	Y_r and y_r axis separation
b	X_r and x_r axis separation
c	Y_p and y_p axis separation
d	X_p and x_p axis separation
μ	X, x scale factor

REV. A

DWG. NO. 124822 SHEET 1 OF 7

REVISIONS

SYM	DESCRIPTION	DATE	BY	APPROVED
A	EXPANDED GENERAL INFORMATION	5-27-63	RM	[redacted]

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Return to: [redacted]

COMPUTER TRANSFORMATION EQUATIONS FOR H-229A PHOTOGRAPHIC RECTIFIER

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BY: [redacted]

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		DATE
DRAWN	RM	4-8-63
CHECKED		
APPROVED		

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TITLE:

CODE IDENT. NO.	SIZE	
83695	A	DWG. NO. 124822
SCALE	UNIT WEIGHT	SHEET 1 OF 7

HMC 1553 REV. 4/61

This report contains and discusses the various equations required for image transformation in the H-229A Photographic Rectifier. The required computations fall into two categories: (1) Transformation of Coordinates, and (2) Control Computations. The coordinate transformation equations included herein will correct distortions due to panoramic effects, tilt, swing, and rotation.

TRANSFORMATION OF COORDINATES

A Magnification

$$Xo = \frac{Xp}{m} \qquad (1)$$

$$Yo = \frac{Yp}{m} \qquad (2)$$

Where:

Xp, Yp	=	Printing Platen Coordinates
Xo, Yo	=	Reference Plane Coordinates
Origin	=	Principal Point
Xaxis	=	Principal Line
m	=	Magnification

B1 Reference Plane Transformations

$$Xrf - \delta x = \frac{Xo \cos \tau \cos S - Yo \sin S}{\sec \tau + \frac{Xo}{f} \sin \tau} \qquad (3)$$

$$Yrf - \delta y = \frac{Xo \cos \tau \sin S + Yo \cos S}{\sec \tau + \frac{Xo}{f} \sin \tau} \qquad (4)$$

Where: Xrf, Yrf = Reading Platen Coordinates for Framing Photography

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τ = Tilt angle

S = Swing Angle between principal line and fiducial marks.

f = focal length

δ = Displacement due to Image Velocity (See following transformations)

NOTE: Compute Equations (3) and (4) assuming $\delta x = \delta y = 0$ to obtain a first approximation of Xrf, Yrf for use in the succeeding equations. Successive approximations can be made until the desired accuracy is achieved.

B2 Image Velocity Displacement

$$\delta x = \frac{V}{H} \quad T \quad \frac{\cos\theta \cos\tau \cos S - \sin\theta \sin S}{\sec\tau + \frac{Xo}{f}\sin\tau} \qquad (5)$$

$$\delta y = \frac{V}{H} \quad T \quad \frac{\cos\theta \cos\tau \sin S + \sin\theta \cos S}{\sec\tau + \frac{Xo}{f}\sin\tau} \qquad (6)$$

Where: $T = \frac{Xrf}{vs}$ or $\frac{Yrf}{vs}$ in framing cameras

$T = \frac{1}{\omega s} \tan^{-1} \frac{(Yrf)}{(f)}$ in panoramic cameras

θ = Angle between the aircraft's course and the principal line

V = Aircraft velocity along the course

H = Aircraft Altitude

vs = Velocity of focal plane shutter curtain

ωs = Angular velocity of panoramic shutter

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C. Framing to Panoramic Transformations

$$Xrp = \frac{Xrf}{\sqrt{1 + \left(\frac{Yrf}{f}\right)^2}} \qquad (7)$$

$$Yrp = f \tan^{-1} \frac{Yrf}{f} \qquad (8)$$

Where: Xrp, Yrp = Reading Platen coordinates for panoramic photography.

NOTE: Compute equations (7) and (8) only when dealing with Panoramic Photography.

CONTROL COMPUTATIONS

Once coordinate trnasformations have been made, additional computations are necessary to obtain control data for the H-229A rectifier. These computations involve algebraic manipulation of the transformed coordinates to define the position and velocity of the X, Y table and the length and rotation of the CRT scan.

Figure 1 is an enlarged segment of a panoramic photograph. The segment shown is bounded by transformed coordinate points Xr1, Yr1 through Xr6, Yr6. Prior to transformation the four corner points defined a one half inch square on the reading platen.

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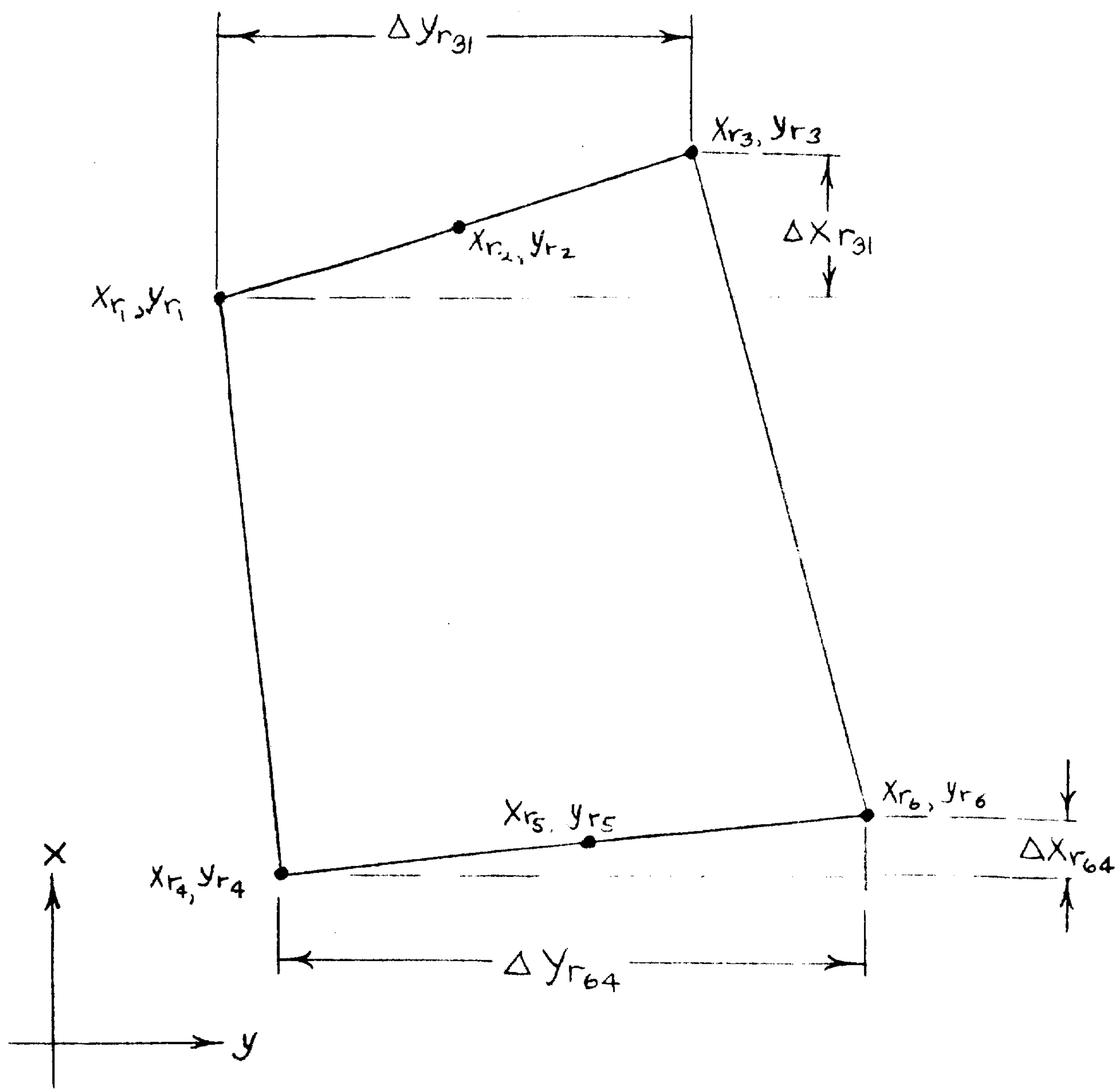

FIGURE 1.

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ALE	UNIT WEIGHT	SHEET 5 of 7

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CONTROL COMPUTATIONS

$$\Delta Xr = Xr3 - Xr1 \qquad (9)$$

$$\Delta Yr = Yr3 - Yr1 \qquad (10)$$

$$\text{Average } \frac{\delta \Delta Xr}{\delta Xp} = \frac{\Delta Xr31 - \Delta Xr64}{Xr2 - Xr5} = \frac{Xr3 + Xr4 - Xr1 - Xr6}{Xr2 - Xr5} \qquad (11)$$

$$\text{Average } \frac{\delta \Delta Yr}{\delta Xp} = \frac{\Delta Yr31 - \Delta Yr64}{Xr2 - Xr5} = \frac{Yr3 + Yr4 - Yr1 - Yr6}{Xr2 - Xr5} \qquad (12)$$

$$\text{Average } \frac{\delta Xr}{\delta Xp} = \dot{X}_r = \frac{1}{\dot{X}_p} (Xr2 - Xr5) \qquad (13)$$

$$\text{Average } \frac{\delta Yr}{\delta Xp} = \dot{Y}_r = \frac{1}{\dot{X}_p} (Yr5 - Yr2) \qquad (14)$$

Where: $\dot{X}p$ is a pre-determined constant.

Xrn, Yrn are transformed coordinates.

GENERAL INFORMATION

The printing platen in the H-229A Rectifier is approximately ten inches square. Along one axis it is ruled off in 1/4 inch intervals and 1/2 inch intervals in the other axis. This defines approximately 800 coordinate points (20 x 40) in the printing platen. For any given rectification, each of the printing platen coordinates must be transformed by the computer into equivalent reading platen coordinates using equations 1 through 8.

The printing platen may be considered as consisting of 400 one half inch squares each bounded by a set of coordinate points. Rectification of these

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squares is performed sequentially with one half second required for each square. The computer must, therefore, compute a new set of Control Data from equations 9 through 14 each one half second.

If the computer is fast enough, it is desirable, but not essential, that all computation be performed on-line. In this mode of operation it will be necessary to transform 6 coordinate points (12 coordinates) and then perform the control computions each 0.5 seconds.

The computer may, on the other hand, pre-compute the transformed coordinates off-line and load them into memory for the control computations which would be performed on-line. In this mode, however, the precomputation time must not exceed four minutes and all of the 800 coordinate points (1600 coordinates) must be computed before control computations are begun.

Input of program constants such as focal length, tilt angle, velocity, etc., to the computer will be in decimal form with seven significant digits. Computer output is to be in pure binary form and both coordinate transformations and control computations must be solved to the fifth decimal place. The range of numbers resulting from solution of coordinate transformation equations will be 0.00000 to 13.99999.

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Research Report
RR-22

GENERAL COMPUTER PROGRAMMING INSTRUCTIONS

FOR THE

[redacted] H-229 PHOTO RECTIFIER

Revised: 23 July 1962

Prepared by:

[redacted]

H229 PROGRAM PREPARATION

CONTENTS

LIST OF ILLUSTRATIONS

1.0 Introduction

1.1 General

This document contains programming instructions for the

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[redacted] H229 Photo Rectifier. Programming a rectification includes computation of set-up data and punching the program tape. This discussion is intended for the H229 equipment operator as well as computing personnel.

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The [redacted] H229 Photo Rectifier (frontispiece) is a photographic printer that exposes the print in a sequence of line and strip scans. Variation of the image reading pattern with respect to the printing pattern permits geometrical changes in the image. The control and electro-optical systems are the basic and unique function in this photographic printer. Figure 1.1 is a block diagram illustrating equipment functions in the rectification of a panoramic photograph.

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